

Application of AMSR-E and MODIS for Monitoring Arctic Tundra Carbon Cycle Dynamics: Recent Results for Alaska Monitoring Stations

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Objectives

- Develop satellite microwave remote sensing measures of surface soil moisture and temperature controls to soil respiration for pan-Arctic vegetation.
- Combine these results with MODIS vegetation products and a simple carbon model to estimate net CO₂ exchange (NEE) and pan-Arctic carbon source/sink activity.
- Verify model accuracies using available biophysical station networks, aircraft flux measurements and detailed ecosystem process model simulations.

Carbon Model Structure

Remote Sensing Inputs:

MODIS:

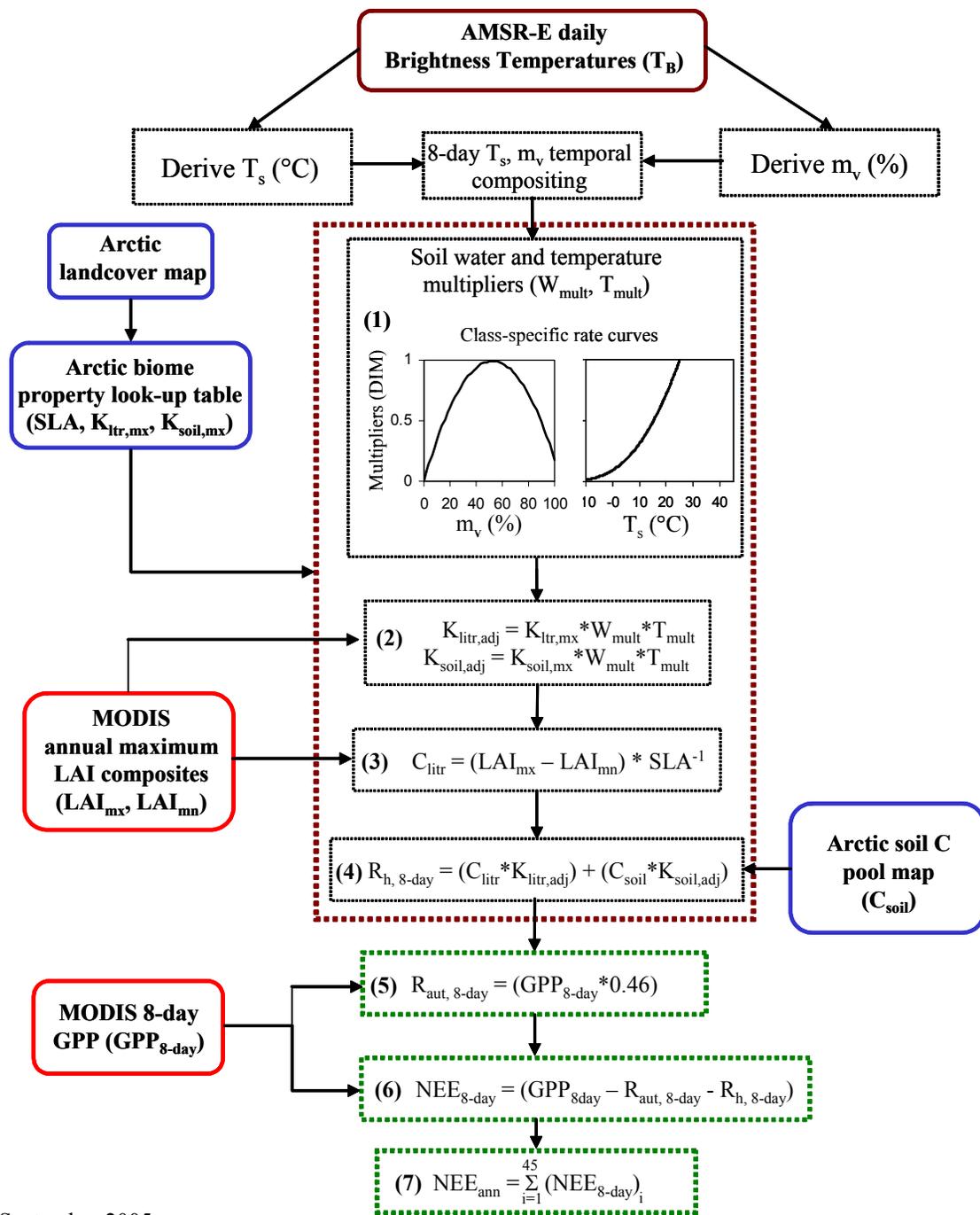
- GPP (8-day, kg C m^{-2})
- Land cover class
- LAI ($\text{m}^2 \text{m}^{-2}$)

AMSR-E:

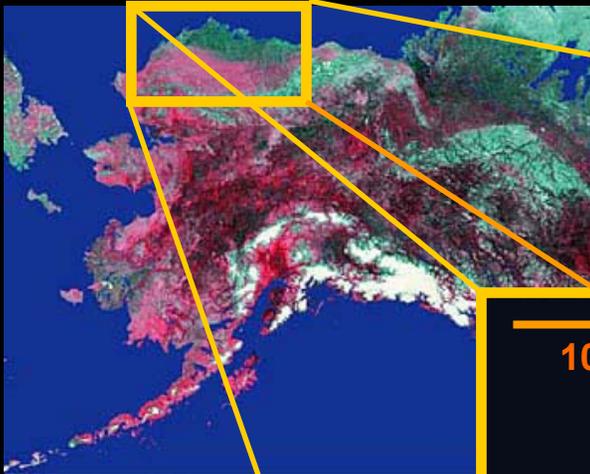
- T_{surface} ($^{\circ}\text{C}$)
- Surface wetness (%)
- Freeze-thaw state

Model Outputs:

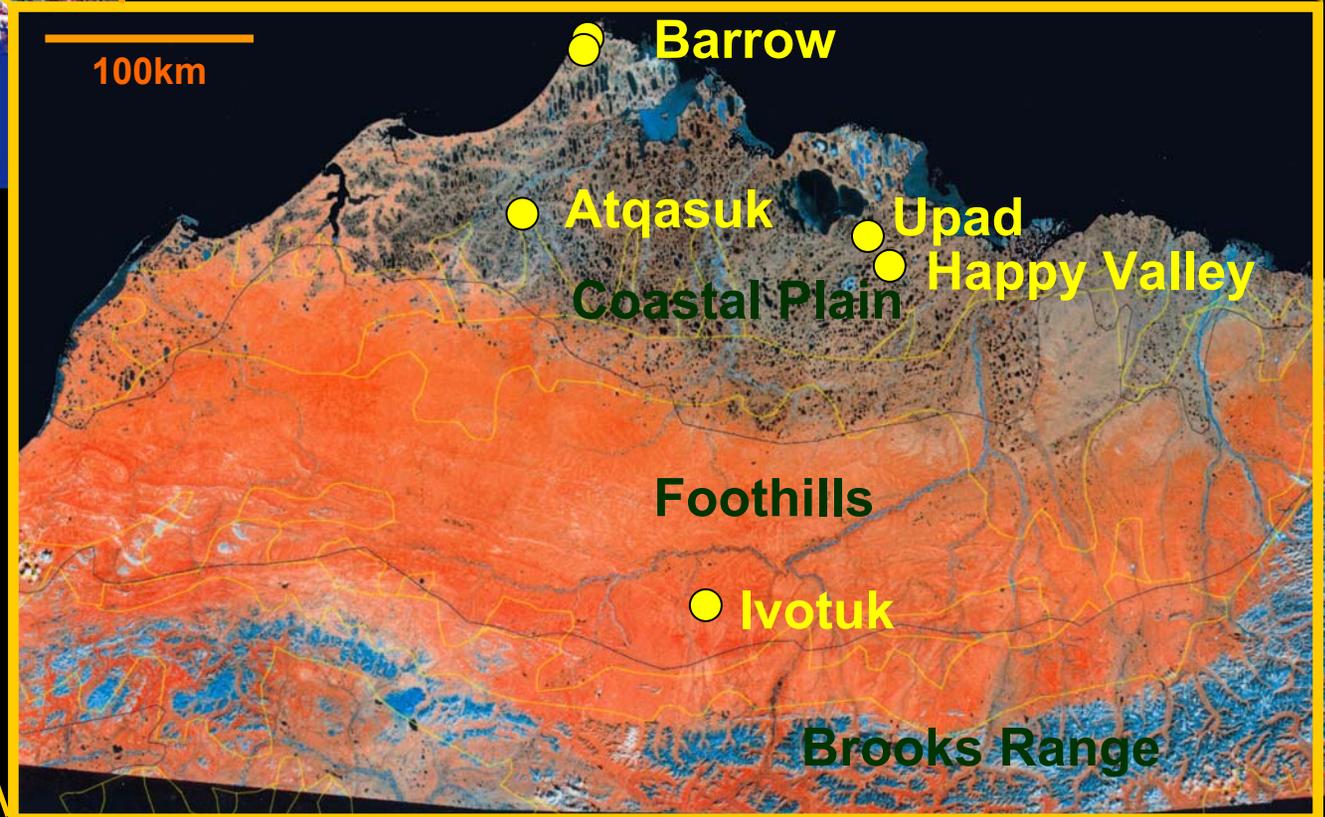
- Autotrophic respiration, R_{aut} (kg C m^{-2} , 8-day/annual)
- Heterotrophic respiration, R_{h} (kg C m^{-2} , 8-day/annual,)
- Net CO_2 exchange, NEE (kg C m^{-2} , 8-day/annual)



Alaska North Slope Study Sites

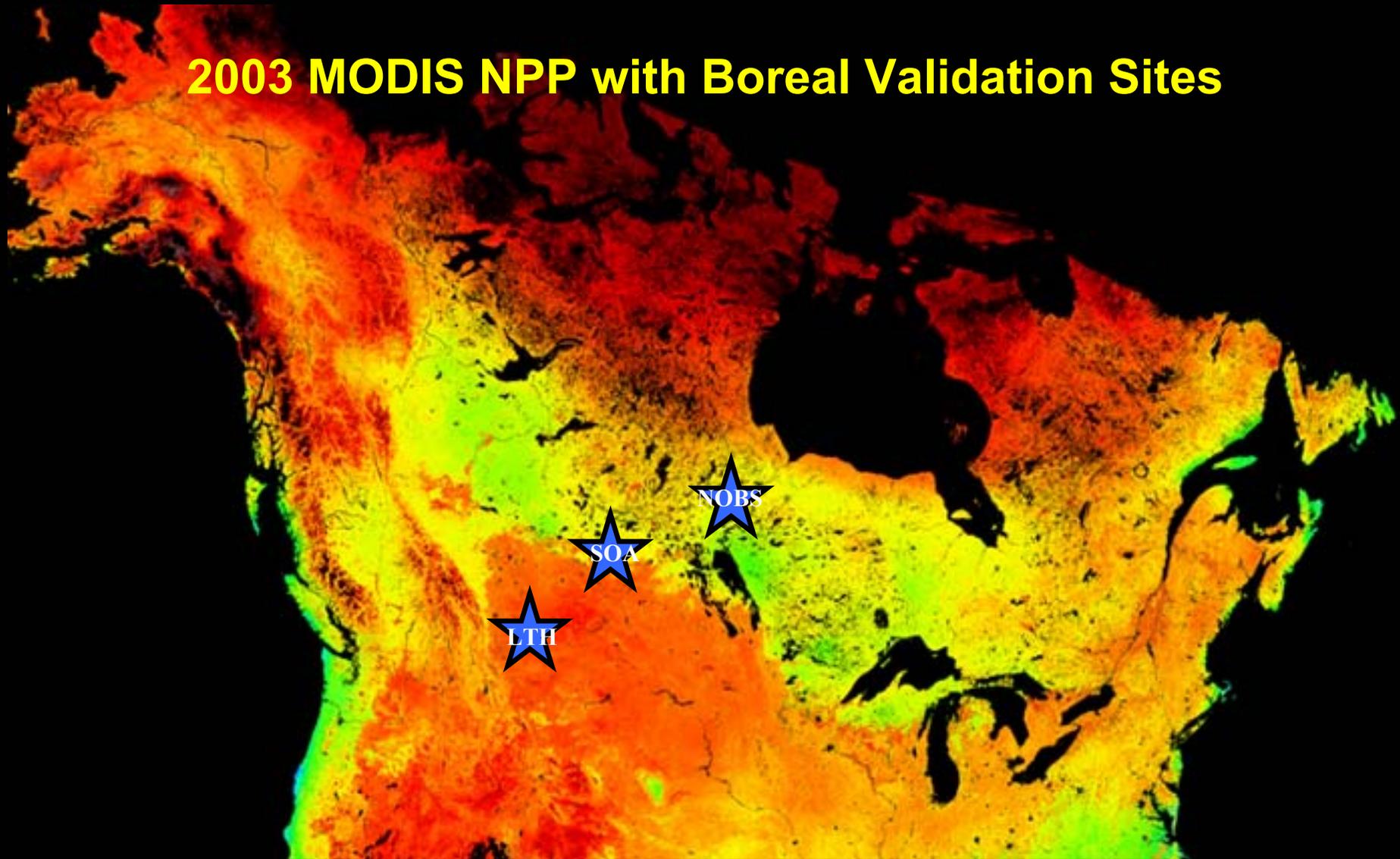


AVHRR, USGS



Landsat MSS 1977-86, Resource Data, Inc.

2003 MODIS NPP with Boreal Validation Sites

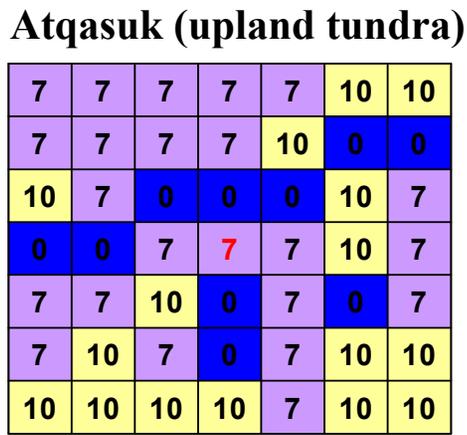
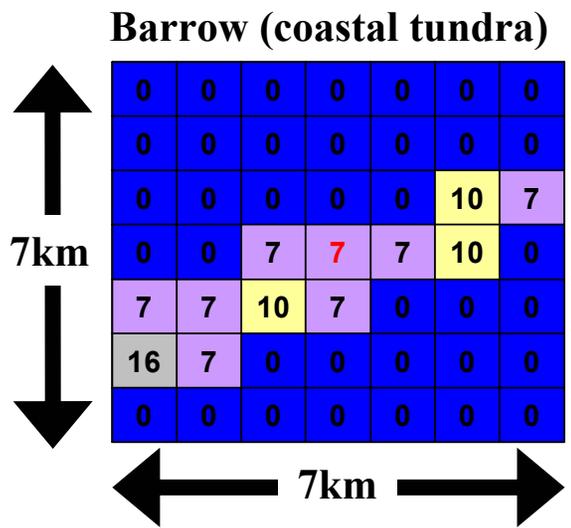


NOBS = Manitoba CN, Boreal evergreen needleleaf forest

LTH = Lethbridge CN, boreal grassland

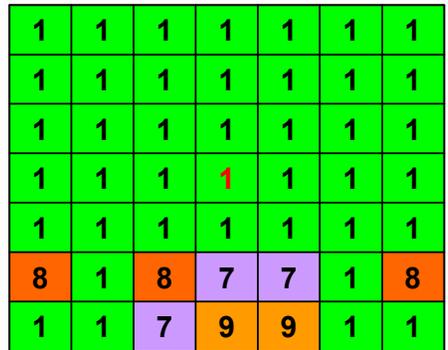
SOA = Saskatchewan CN, Boreal deciduous broadleaf forest

MODIS Land Cover Class Heterogeneity over Tower Sites

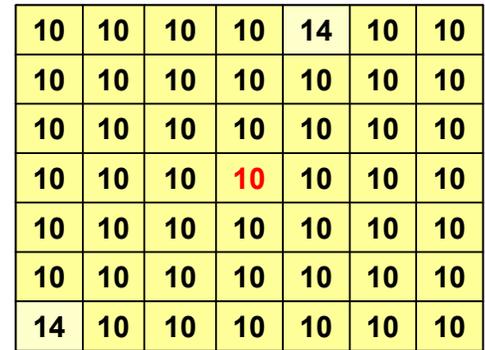


- 0 = Water
 - 1 = Evergreen needleleaf forest
 - 7 = Open Shrubland
 - 8 = Woody Savanna
 - 9 = Savanna
 - 10 = Grasslands
 - 14 = Cropland
 - 16 = Barren or Sparsely Vegetated
- Red Font denotes Tower Location**

NOBS (boreal forest)



Lethbridge (boreal grassland)



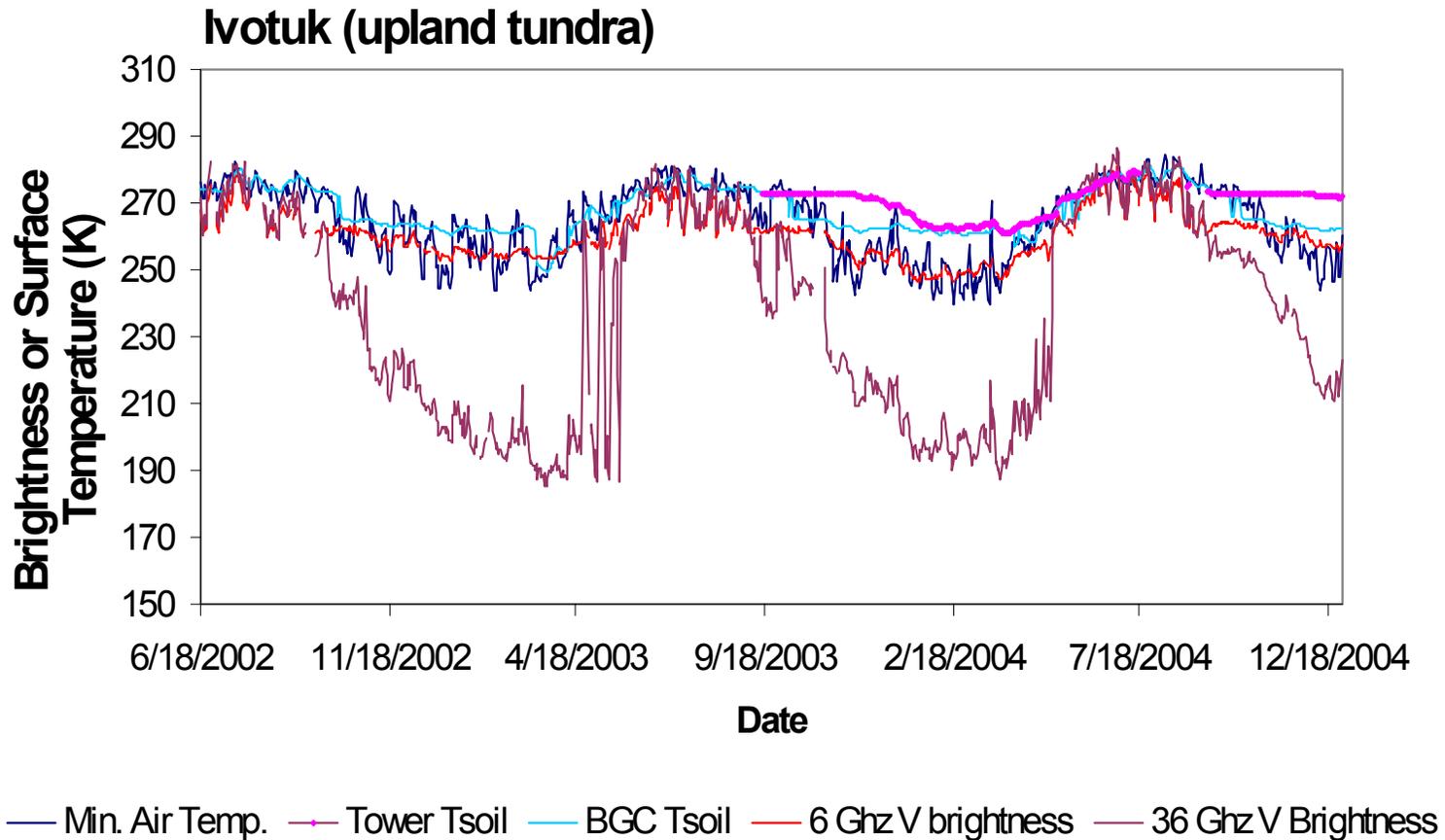
Surface Temperature Estimation from AMSR-E

Steps:

1. Extract AMSR-E orbital swath data over validation sites using radius distance threshold approach;
2. Apply temporal edge detection algorithm to identify frozen/non-frozen periods from T_b data stream;
3. Evaluate ascending and descending overpass data, individual bands and polarizations using site based air and soil ($\sim 10\text{cm}$ depth) temperature data;
4. Evaluate/compare alternative approaches for computing T_b based surface temperatures, including ¹Fily and Emissivity look-up table (LUT) methods.

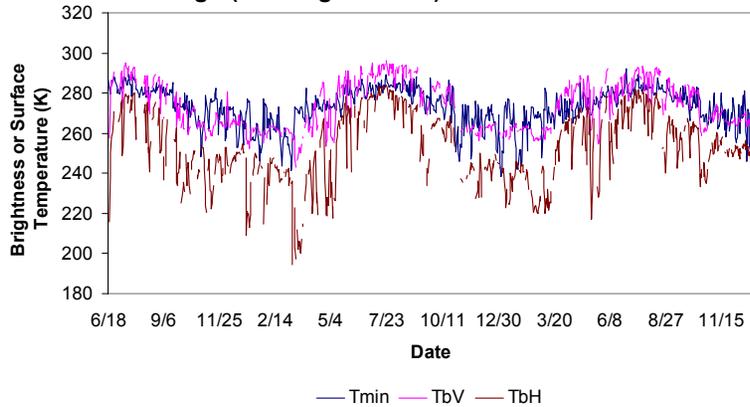
¹Fily, M., et al., 2003. *Rem. Sens. Environ.* 85, 328-338

AMSR-E Tb comparison to Site Temperature (6.9 and 36.5 GHz, V-pol)

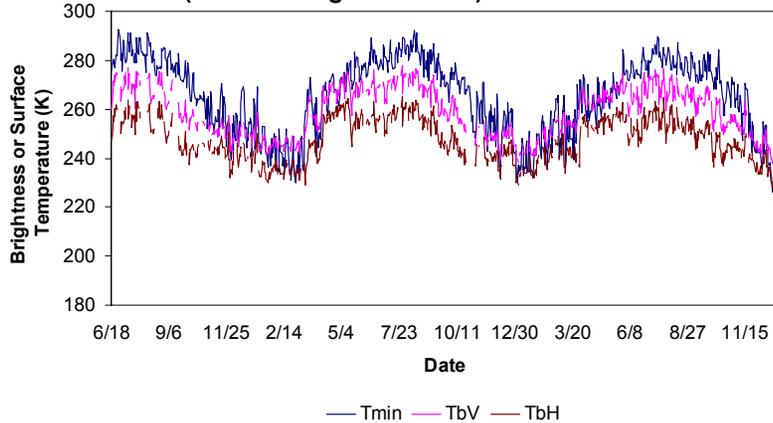


AMSR-E 6.9 GHz (V/H) Tb and Site Surface Temperature Comparisons

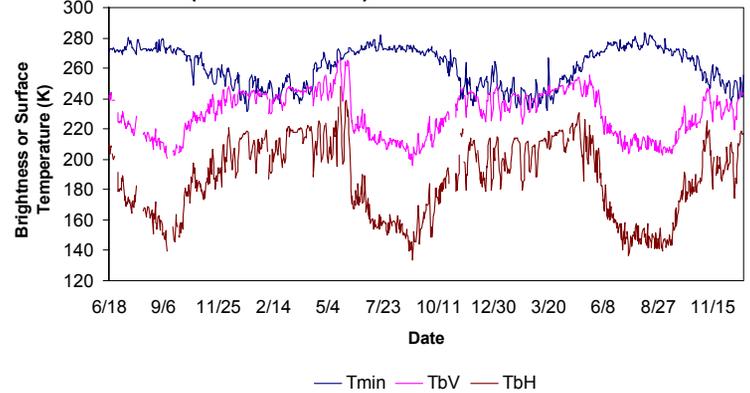
Lethbridge (boreal grassland)



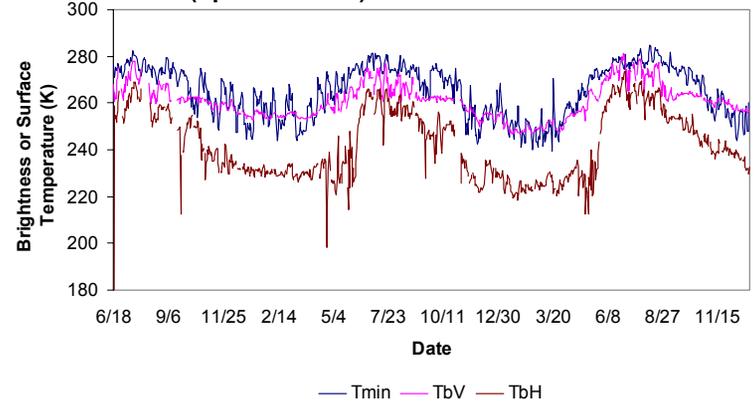
NOBS (boreal evergreen forest)



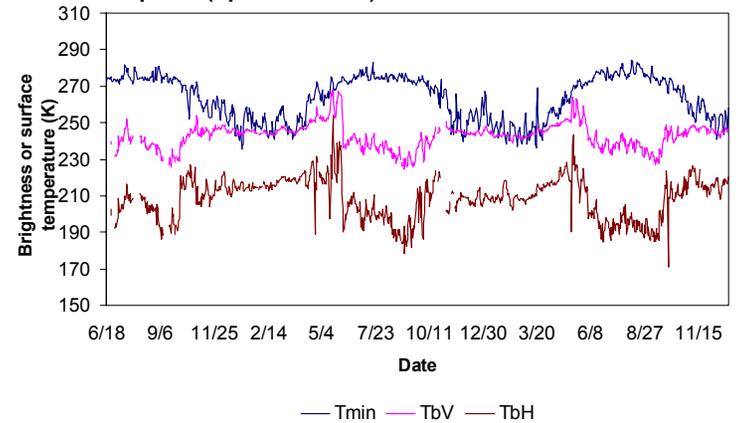
Barrow (coastal tundra)



Ivotuk (upland tundra)



Atqasuk (upland tundra)



Emissivity LUT Development Using AMSR-E 6.9 GHz Tb and Site Temperature Data

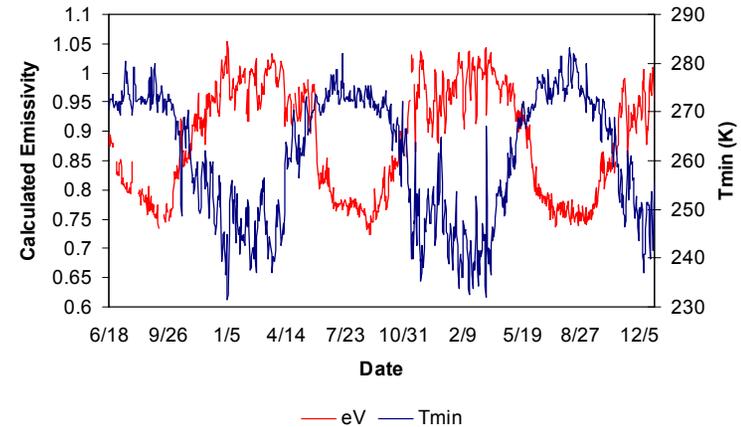
Calculated Emissivities:

$$eV = T_bV / T_{min}$$

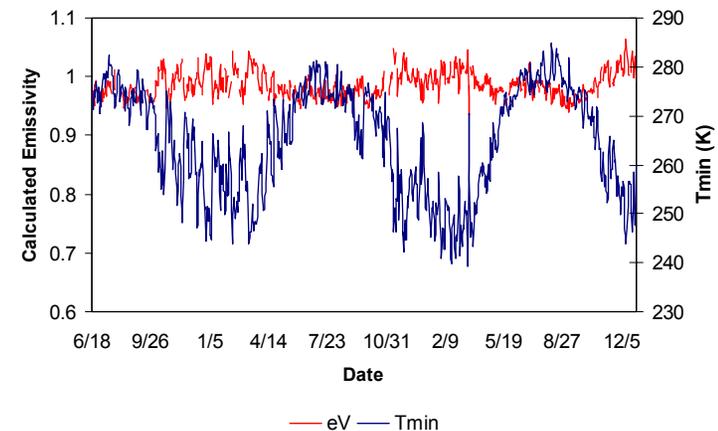
Site	Thawed		Frozen	
	Mean	Stdev.	Mean	Stdev.
Barrow	0.800	0.455	0.965	0.039
Atqasuk	0.867	0.026	0.969	0.027
Ivotuk	0.975	0.022	0.998	0.016
NOBS	0.967	0.024	0.986	0.031
LTH	1.012	0.024	0.989	0.036

- Emissivity calculations derived from site Tmin measurements due to scarcity of Tsoil data, resulting in $e > 1$ at 6.9GHz in some instances (e.g., $T_{min} < T_s$).

Barrow (coastal tundra site)

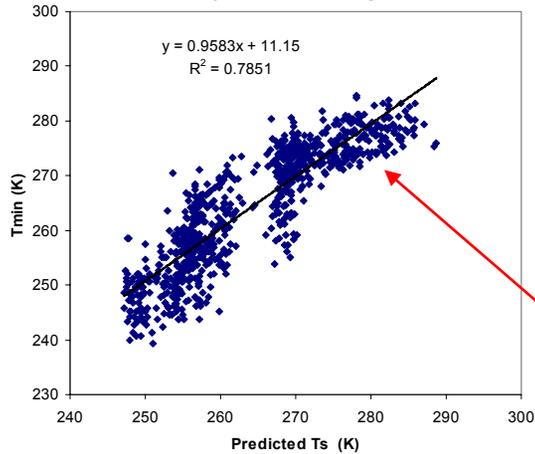


Ivotuk (upland tundra site)

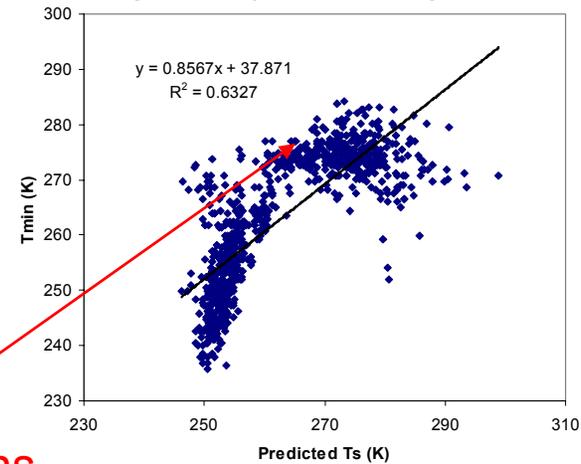


Accuracy of Emissivity LUT Approach Degrades with Increasing Open Water Coverage

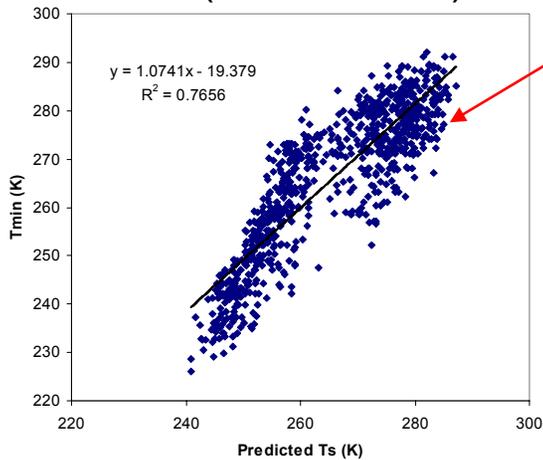
Ivotuk (inland upland tundra)



Atqasuk (coastal upland tundra)

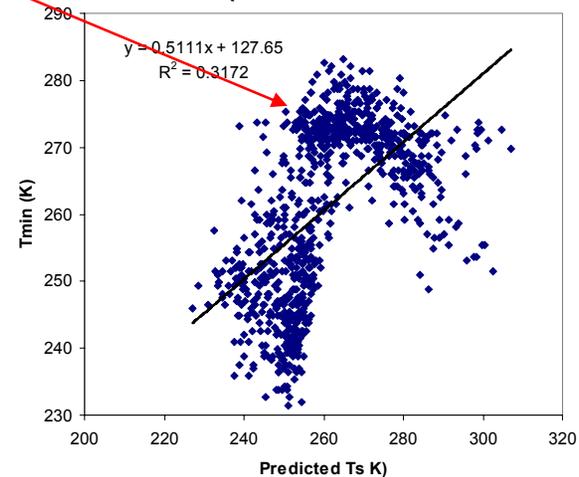


NOBS (boreal forest)

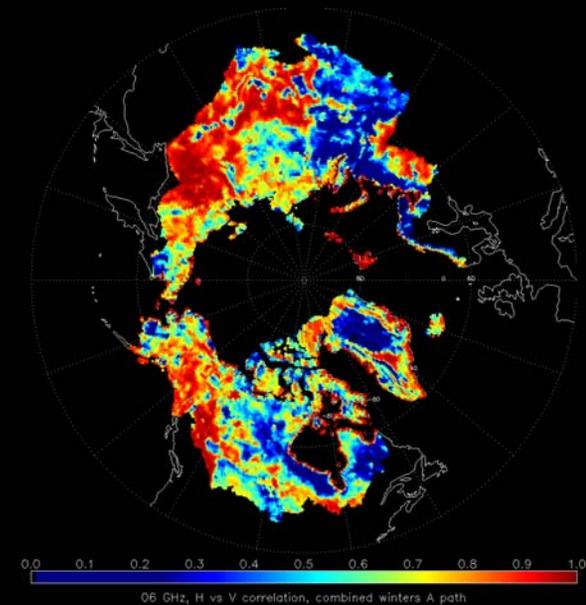
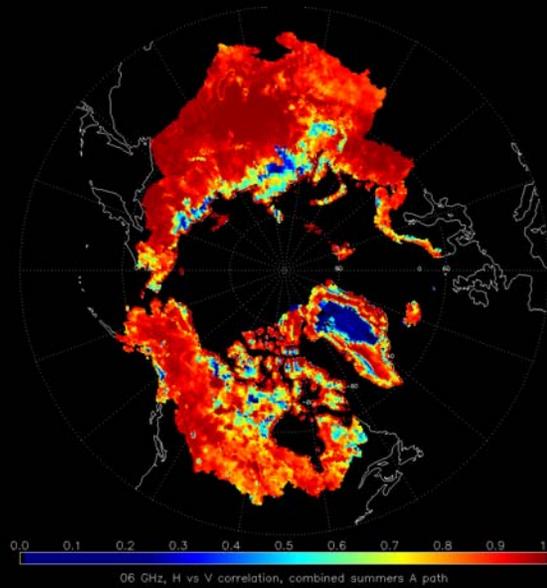


Thawed conditions

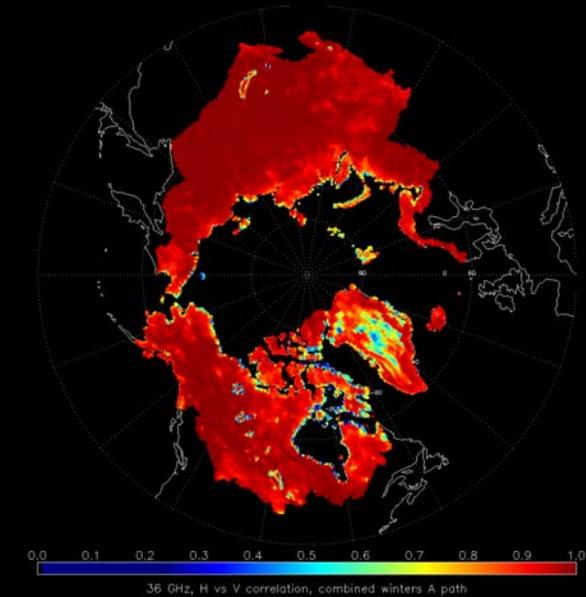
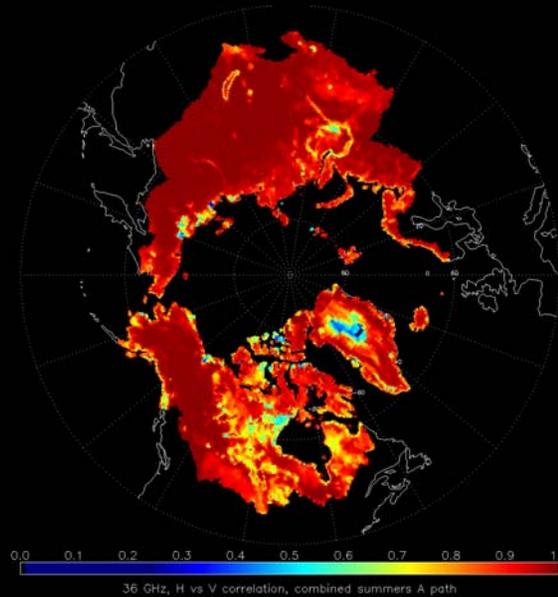
Barrow (coastal lowland tundra)



AMSR 6.9 GHz H vs V Correlation



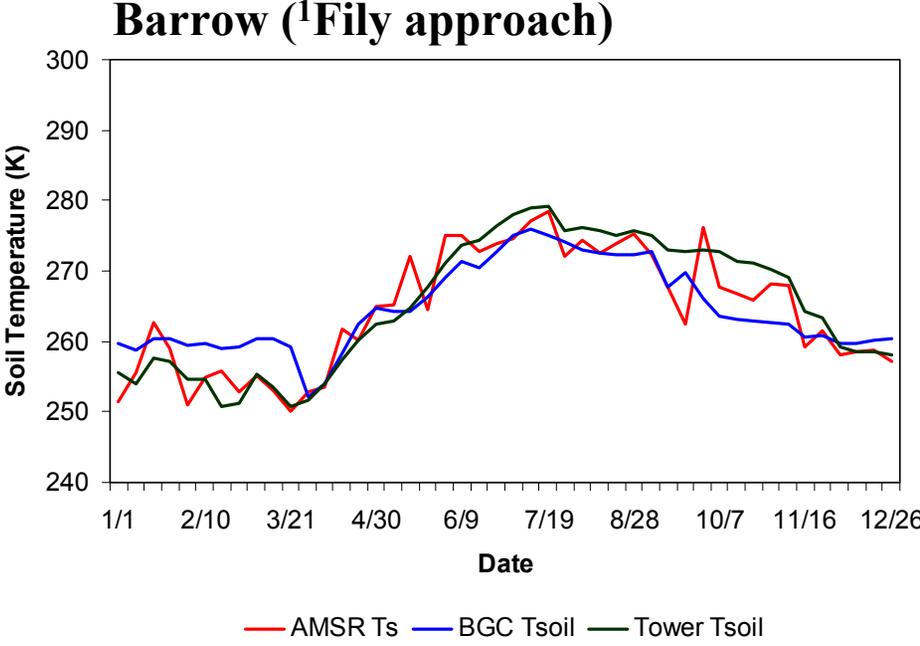
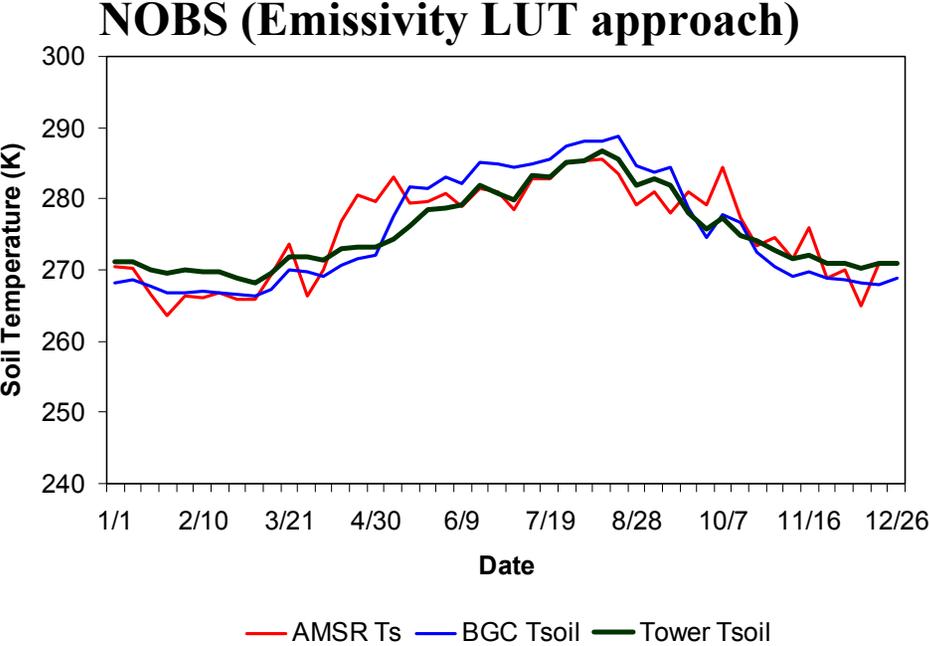
AMSR 36.5 GHz H vs V Correlation



Summer

Winter

Soil Temperature Comparison: AMSR-E 6.9 GHz Results vs Site Measurements (2003, 8-day average)



¹Fily, M., et al., 2003. *Rem. Sens. Environ.* 85, 328-338

AMSR Ts Model Performance Summary (6.9 GHz)

Emissivity LUT Method:

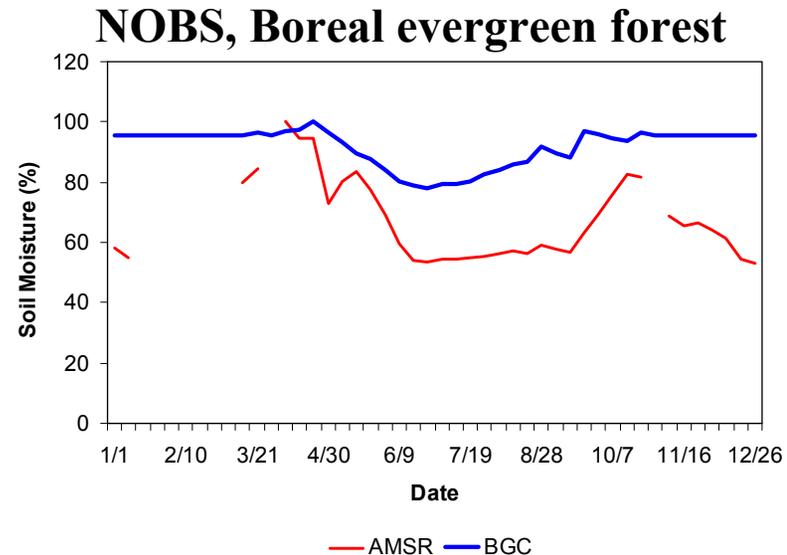
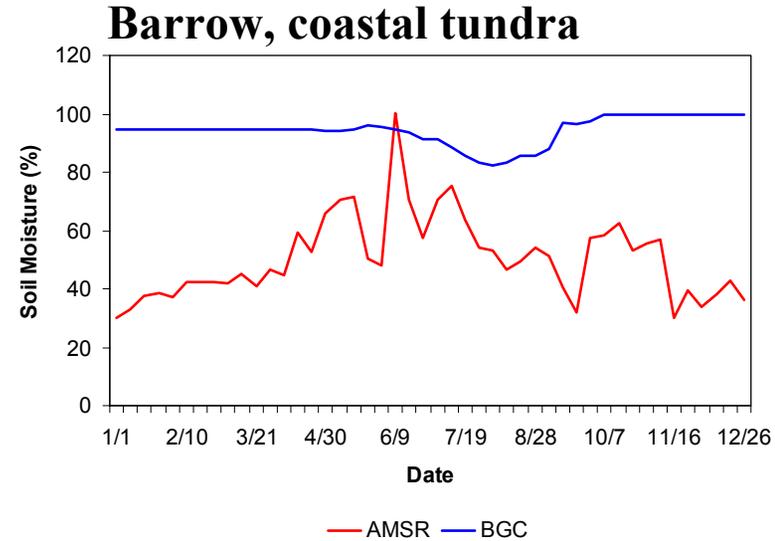
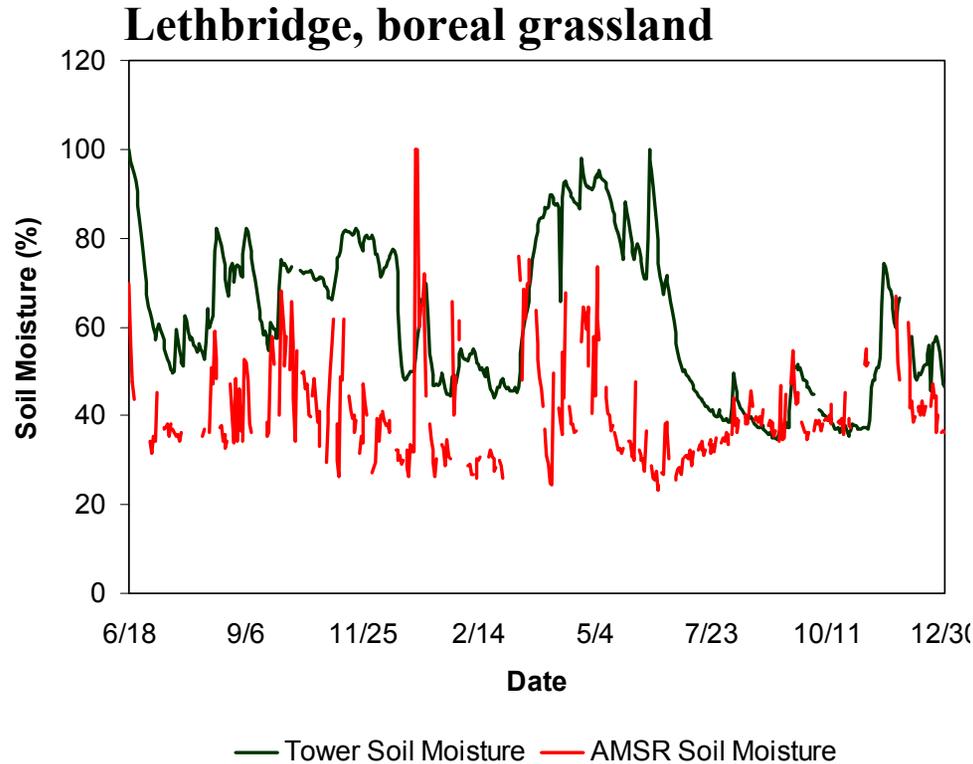
Site	R ²	MR*	STE*	MAE*	P
Barrow	0.32	0.25	11.77	10.37	<0.0001
Atqasuk	0.63	0.15	7.30	5.75	<0.0001
Ivotuk	0.73	1.27	4.97	4.78	<0.0001
NOBS	0.77	0.26	5.99	6.08	<0.0001
LTH	0.41	0.11	7.45	6.25	<0.0001

Fily Method:

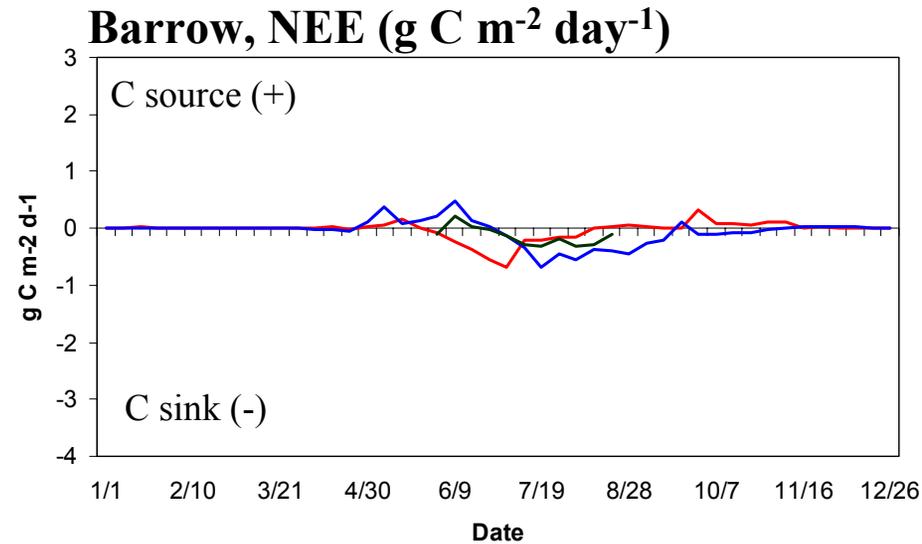
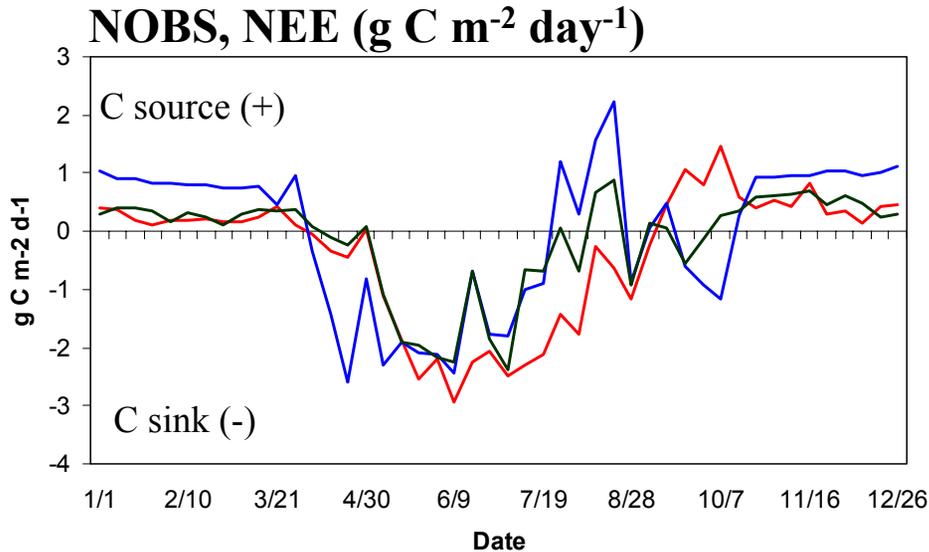
Site	R ²	MR*	STE*	MAE*	P
Barrow	0.67	0.093	7.55	5.92	<0.0001
Atqasuk	0.43	2.82	8.60	7.60	<0.0001
Ivotuk	0.72	0.10	5.72	4.62	<0.0001
NOBS	0.54	-1.49	14.47	10.49	<0.0001
LTH	0.54	1.01	6.20	5.37	<0.0001

* MR= Mean Residual = $\Sigma(\text{Site } T_{\text{min}} - \text{AMSR } T_s)/n$; STE= Standard Error; MAE = Mean Absolute Error

Surface Soil Moisture Comparison: AMSR-E L3 vs Site Measurements (2003, 8-day average, % saturation)



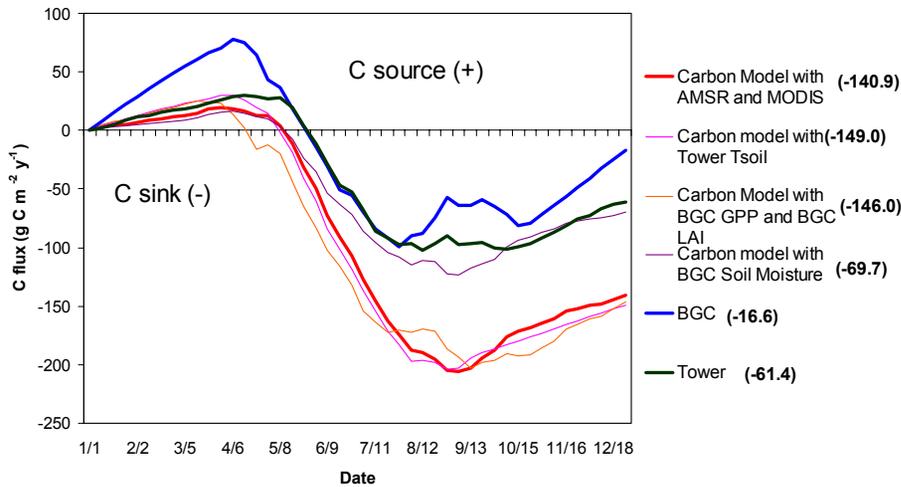
MODIS/AMSR Carbon Model Evaluation over Tower Sites (2003, 8-day average)



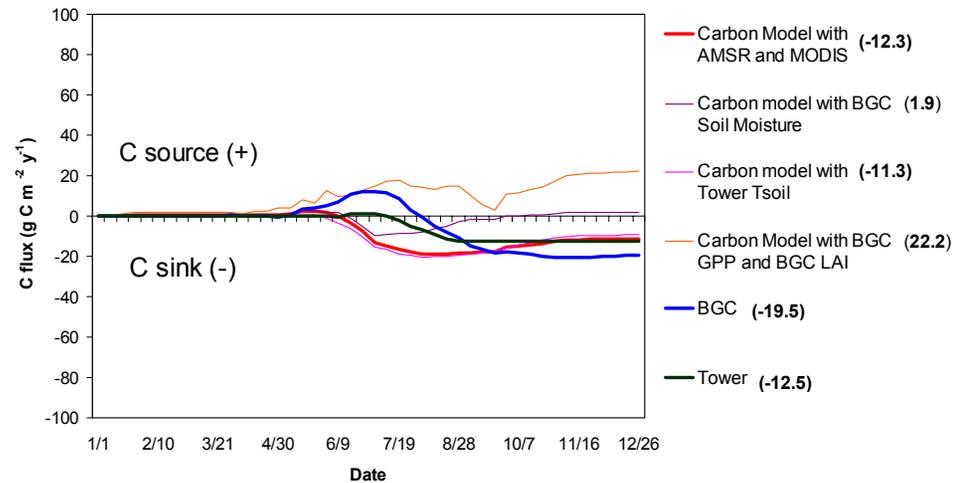
- Carbon model results derived from MODIS LAI, GPP and AMSR-E 6.9 GHz T_s and L3 soil moisture inputs
- Biome-BGC ecosystem process model simulations using site meteorology
- Tower CO₂ eddy flux measurement based results

MODIS/AMSR Carbon Model Evaluation over Tower Sites (2003, 8-day average)

NOBS cumulative NEE (g C m⁻² day⁻¹)



Barrow cumulative NEE (g C m⁻²)



- Carbon model results derived from MODIS LAI, GPP and AMSR Ts and SM inputs
- Carbon model results derived from MODIS LAI, GPP and tower Ts measurements
- Carbon model results derived from Biome-BGC LAI, GPP and AMSR Ts and SM
- Carbon model results derived from Biome-BGC SM, MODIS GPP, LAI and AMSR Ts
- Biome-BGC ecosystem process model simulations using site meteorology
- Tower CO₂ eddy flux measurement results

Current Findings

1. AMSR-E 2002-2004 Tb based surface temperatures compare favorably with site based temperatures:
 - Sensitivity to air and soil temperatures depends on wavelength, snowcover and freeze-thaw dynamics and subgrid scale extent of open water;
 - Ts estimation using simple emissivity LUT approach is comparable to more detailed approaches for most sites.
2. AMSR-E L3 soil moisture data show large discrepancies relative to site-based ecosystem model simulations and limited measurements:
 - Differences larger in winter than summer;
 - Other differences attributed to greater AMSR sensitivity to surface soil layers relative to Tsoil measurements at greater (5-20cm) depths.
3. Carbon model results are generally consistent with site based CO₂ flux measurements and detailed ecosystem process model simulations:
 - Model generally represents NEE seasonal variability and regional patterns;
 - Model NEE is highly sensitive to LAI, which determines optimal soil decomposition rate;
 - NEE is a residual of two larger fluxes, GPP and R_{tot}; small changes in component fluxes yield large changes in annual NEE and predicted carbon source/sink behavior, especially for relatively low productivity sites such as tundra.

Next Steps

- Update MODIS and AMSR-E data streams, biophysical network data and ecosystem model simulations through 2005.
- More detailed assessment of AMSR-E soil moisture; evaluate alternative algorithms, spectral bands and polarizations over available station networks;
- More detailed carbon model sensitivity analysis of LAI, soil carbon pool, Ts and SM inputs;
- Apply an open water mask within modeling framework and evaluate AMSR land information extraction potential for contaminated pixels.
- Regional application of carbon model across pan-Arctic basin to assess regional patterns and annual anomalies.
- Coordinate modeling activities with other regional experiments: NSF Arctic biocomplexity study at Barrow (2006); Hydros OSSE at BOREAS (2005-06); NASA Cold Land Processes Experiment Alaska campaign (March, 2006).